

Computer-Based Post-Stroke Rehabilitation of Prospective Memory[☆]Antonija Mitrovic^{a,*}, Moffat Mathews^a, Stellan Ohlsson^b, Jay Holland^a, Audrey McKinlay^c^a Intelligent Computer Tutoring Group, University of Canterbury, New Zealand^b Department of Psychology, University of Illinois at Chicago, United States^c Department of Psychology, University of Melbourne, Australia

Abstract

We present a computer-based environment for rehabilitation of prospective memory in stroke survivors. Prospective memory (PM), or remembering to perform actions in the future, is of crucial importance for everyday life. This kind of memory is often impaired in stroke survivors and can interfere with independent living. Fifteen participants were recruited to participate in our study consisting of 10 sessions. The participants were first trained on how to develop visual images in order to remember time- and event-based prospective memory tasks. After the visual imagery training, participants practiced their PM skills using videos, and later in a virtual reality (VR) environment. The results show a significant improvement on PM skills as measured by the CAMPROPT test, which remained stable 4 weeks after the treatment. VR-based training was well accepted by the participants.

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Stroke is the second leading cause of death and a major contributor to disability (Gommans et al., 2003; World Health Organization, 2015). Cognitive impairment plays a crucial role in determining the broader outcomes of a stroke survivor (Barker-Collo et al., 2009; Hochstenbach, Anderson, van Limbeek, & Mulder, 2001). The extent of impairment directly affects aspects of daily functioning (Patel, Coshall, Rudd, & Wolfe, 2002; Zhu et al., 1998), and often necessitates constant care. Customized rehabilitation, performed by trained medical staff, is required but is labor-intensive and expensive (DeJong, Horn, Conroy, Nichols, & Heaton, 2005). Neuropsychological research suggests that appropriate cognitive training could improve functioning, remediate core deficits, and positively affect quality of life (Barker-Collo et al., 2009; Gaggioli, Meneghini, Morganti, Alcaniz, & Riva, 2006; Medalia, Aluma, Tryon, & Merriam, 1998; Wolinsky et al., 2006, 2009).

The problem faced in the field of brain injury is two-fold. First, to further neuropsychological research, different types of training need to be applied to large samples of patients (Grealy, Johnson, & Rushton, 1999), requiring significant clinical input and resources. As a result, guidelines used by clinicians to provide specialized care have been criticized as being based more on expert opinion than on empirical evidence (Rohling, Faust, Beverly, & Demakis, 2009). Second, once the ideal training has been determined, it has to be accessible cost effectively to all patients, anytime, anywhere, and at their level and pace. Presently, these goals are not achievable, and rehabilitation research and practice focus on managing disabilities rather than improving cognitive outcomes. Therefore, research on developing effective computer-based cognitive rehabilitation is of high importance.

Stroke survivors and brain-injury patients often have severely impaired prospective memory (Brooks, Rose, Potter, Jayawardena, & Morling, 2004; Mathias & Mansfield, 2005). Prospective memory, or remembering to perform actions in the future, is of crucial importance for everyday life (Ellis & Kvavilashvili, 2000; Titov & Knight, 2000). PM failure can interfere with independent living,

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as it can result in forgetting to take medication, switch off the stove, or missing doctor's appointments. It is a complex cognitive ability, which requires coordination of multiple cognitive abilities: spatial navigation, retrospective memory, attention and executive functioning (Knight & Titov, 2009).

There is a distinction between event-, time- or activity-based PM (Fish, Wilson, & Manly, 2010; Kvavilashvili & Ellis, 1996). In the case of a time-based task, a certain task needs to be performed at a certain time (e.g. having a dentist's appointment at 3pm). In event-based tasks, a task needs to be performed when a certain event happens (e.g. returning a book to a friend when we see them next). Finally, in an activity-based task, one needs to perform a task after or before performing another task that together could be defined as parts of an activity (e.g. switching off the stove after finishing cooking).

To be able to perform a task in the future, a person needs to know the task (retrieved from the retrospective memory), a level of intention, and a cue. Cues are prompts that help people remember the tasks to be performed in the future. Einstein and McDaniel (1990) explain how cues help the process of remembering. When a person perceives a cue, it delivers the information that was previously associated with the cue to the consciousness, and the person remembers the task. Previous research indicates that cues help a person's prospective and retrospective memory as it reinforces their intention to execute a task (Gollwitzer, 1996). A procedure to test PM requires an on-going task in which a person is absorbed, with pre-designated cues appearing randomly, requiring corresponding actions to be performed (Knight, Titov, & Crawford, 2006).

Prospective memory is very difficult to assess using neuropsychological tests as conventional tests consist of simple, abstracted activities divorced from the complexity of real-world tasks. In order to assess PM, it is necessary to obtain information about how a patient functions in everyday life, which is difficult to achieve in laboratory settings. Research shows that scores from neuropsychological tests often cannot be translated to conclusions about the level of impairment and therefore rehabilitation goals because many conventional tests lack ecological validity (i.e. similarity with real life) (Knight & Titov, 2009). It is therefore necessary to replace such tests with tasks that mirror real-world activities (Brooks & Rose, 2003; Burgess et al., 2006; Knight & Titov, 2009). However, assessing patients in real-world situations entails logistic problems and is not achievable in rehabilitation units (Brooks et al., 2004). When real-life tasks are performed in the laboratory settings, they still may have low ecological validity, as visual and auditory distractions are usually minimized (Knight et al., 2006).

In the last decade, many research projects have used virtual reality (VR) in neuroscience research and therapy (Bohil, Alicea, & Biocca, 2011), ranging from the use of VR for assessing cognitive abilities, over neuro- and motor rehabilitation to psychotherapy, such as treatment of phobias. VR environments are computer-generated environments that simulate real-life situations and allow users to interact with them. They provide rich, multisensory simulations with a high degree of control and rich interaction modalities. They can also have a high level of ecological validity. VR has been used for assessment of PM in patients with traumatic brain injury (TBI) (Knight & Titov, 2009) and stroke patients (Brooks et al., 2004). VR is suited for PM as it supports complex, dynamic environments that require coordination of many cognitive abilities.

Although there has been some research done on how to assess PM, there is very little available on rehabilitation strategies for PM (Shum, Fleming, & Neulinger, 2002; Yip & Man, 2013). Some studies have focused on strengthening retrospective memory with Alzheimer's patients, but using the spaced retrieval technique (Camp, Foss, O'Hanlon, & Stevens, 1996) and errorless learning (Kixmiller, 2002). Sohlberg, White, Evans, and Mateer (1992) reported on a study, which involved a small number of patients with acquired brain injury being involved in repeated practice of tasks over increasing delay periods. This approach requires a lot of practice over a long period, with the increase in delay of 4–8 min. The reported success rate ranged from 40% to 80%, but the gains did not generalize to activities outside the clinic setting (Sohlberg & Mateer, 1989). Another approach reported in (Fleming, Shum, Strong, & Lightbody, 2005) involved an intervention of compensatory type: it focused on increasing awareness of the impaired PM and use of compensatory strategy (a diary). They performed three case studies with small numbers of participants, and although there was a gain, there was a lack of adequate controls. In a follow up study with TBI adults, Shum, Fleming, Gill, Gullo, and Strong (2011) investigated the effects of a compensatory strategy and self-awareness training compared to active controls, and found larger improvement in PM for participants who had compensatory PM training, even though the intervention was short (eight weeks) and of low intensity.

Yip and Man (2013) involved 37 participants with acquired brain injury in 12 sessions of PM training using non-immersive VR. The participants were asked to perform a set of event- and time-based PM tasks in parallel with an ongoing task. The PM training was based on remedial and process approaches. The remedial approach provided repetitive exercise within the VR environment. The process approach, on the other hand, aimed to support multiple facets of PM, and supported encoding of intention, retention, and performance interval and recognition of cues. Participants were given a list of four shopping items they needed to memorize, and their recall was tested before entering the VR environment where they needed to perform the tasks. The VR training showed significant improvement in participants' immediate recall of PM tasks, performance on both time- and event-based tasks as well as ongoing tasks, and a significant improvement in self-efficacy.

Visual imagery has also been studied as an approach to improving memory. It is a technique in which the participant forms a visualization of a given word. The same strategy can also be used to make a visualization of a pair of words, by linking the words and making the visualization as unusual as possible to make it more memorable. Previous work (Lewinsohn, Danaher, & Kikel, 1977) has shown that visual imagery improves retrospective memory. McDaniel and Einstein (1992) showed that PM performance improved when participants were given pictures of targets, or when participants formed mental images of cues.

Potvin, Rouleau, Sénéchal, and Giguère (2011) investigated the effectiveness of visual imagery techniques in PM rehabilitation. They developed training based on visual imagery, which strengthens the cue-action association. Ten TBI patients were trained to form mental images, which associate cues with intended actions in a series of more complex tasks, over ten weeks (one 90-min session per week). In the early sessions, participants were taught how to visualize simple objects presented visually or orally. In a later session, the participants learnt to apply visual imagery in PM and in everyday situations. This experimental group was then compared to a group of 20 TBI patients who received a standard intervention consisting of a short session explaining various compensatory strategies. The participants who were trained in visual imagery improved their performance on the PM experimental tasks and also reported fewer PM failures in everyday life.

Our aim was to develop a computer-based environment for rehabilitation of PM in stroke survivors. We have developed a computer-based training, which teaches participants how to remember PM tasks using visual imagery. After undergoing the training, participants practiced their PM skills in a non-immersive VR environment. Our first hypothesis was that the visual imagery training would enable the participants' PM to gradually improve while practicing in the VR environment. We also hypothesized that at the end of our treatment there would be a significant improvement of PM skills of stroke survivors, for both time- and event-based tasks (hypothesis 2). In this paper, we report on a recently conducted study with 15 stroke survivors.

Method

Participants

We recruited 15 participants from stroke clubs (self-help groups for stroke survivors). The inclusion criteria were: (1) Have suffered from a stroke at least six months prior the study; (2) Adequate or corrected hearing and vision; (3) English as the primary spoken language. Exclusion criteria were: (1) History of moderate or severe head injury; (2) Major neurological impairment; (3) Major medical illness other than having suffered a stroke; (4) Significant psychiatric illness requiring hospitalization; (5) Diagnosis of, or special education for, a learning disability; (6) Major depressive episode in the previous 6 months; (7) Pre-morbid IQ estimated at <85 using National Adult Reading Test (NART¹). Informed consent was obtained from all participants according to the guidelines of the Human Ethics committee of the University of (name removed for the blind review). The selected participants received a supermarket or petrol voucher of \$20 at each session. The study was performed over several months, with the final sessions taking place in mid-October 2014.

Neuropsychological tests

A battery of tests was used to evaluate cognitive functions generally disrupted after a stroke. Tests 1–7 below were used to screen the participants in relation to the inclusion and exclusion criteria, while the last two tests were used as PM measures. A postgraduate Psychology student administered the following tests in Session 1:

1. *Short-term and working memory*: Digit span test (digits forward and reversed) from the Wechsler Adult Intelligence scale WAIS-IV (Wechsler, 2008) was used to assess short-term and working memory and required the participant to repeat (either in forward or reverse order) an increasing string of verbally presented digits. The cut-off point for digit forwards was <4. For digits forward, the participants scored the mean of 9.13 (sd = 2.67), while the mean for digits backwards was 5.2 (sd = 1.37).
2. *Premorbid intellectual ability*: The National Adult Reading Test (NART) provides a brief estimate of full-scale IQ (Nelson & Willison, 1991), and comprises a list of 50 irregular words (irregular in terms of pronunciation to reduce the possibility of reading by phonemic decoding). Participants were required to read individual words presented on a computer screen. Words were scored 0 for incorrect pronunciation and 1 for correct pronunciation. Raw scores were then converted to estimate premorbid IQ scores (instructions on how to calculate these transformations are contained in the instruction manual). All of our participants scored above 85 (the cut-off score), with a mean score of 118.13 (sd = 7.37).
3. *Depression, Anxiety and Stress Scale (DASS)*: The DASS is a 42-item self-report instrument designed to measure the three emotional states of depression, anxiety and tension/stress by using a 4-point Likert scale, ranging from 0 to 3. Higher scores indicate higher levels of the emotional states (Lovibond & Lovibond, 1995). All participants met this inclusion criterion.
4. *Current cognitive status*: The Mini Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975) is a brief objective screening instrument of current cognitive status, consisting of items that test an individual's orientation to time and place (10 points), registration, attention and short-term memory (11 points) and language (9 points). Items are scored as correct or incorrect. Scores can range from 0 to 30, with lower scores indicating greater impairment. For this study, a score of >25 was defined as "no signs of overt dementia" as part of the initial exclusion criteria. The mean score for our participants was 27.8 (sd = 2.18). The additional 4 categories (date and place of birth, word fluency, similarities, delayed recall of words) used in the 3MS were also

¹ www.academia.edu/2515150/National_Adult_Reading_Test_NART_test_manual_Part_1#.

- administered and scored according to standard guidelines (Teng & Chui, 1987). Scores for the 3MS range can range from 0 to 100, with lower scores indicating greater deficits. A cut-off of <78 is considered sensitive for detecting early signs of Alzheimer's and was used for this study (Tombaugh, 2005). No participants scored below the cut-off on 3MS, with the mean of 93.8 (sd = 5.61). Two participants with a low MMSE score (23 and 24) scored above the cut-off on 3MS, and therefore met the inclusion criteria.
5. Visual Association Test (VAT) is a brief learning task based on imagery mnemonics and was used to screen for anterograde amnesia (the ability to create new memories) (Lindeboom, Schmand, Tulner, Walstra, & Jonker, 2002). Participants were initially shown six cue cards with line drawings of familiar objects (e.g. a monkey). Next, the participant was shown six "association cards" with new interactions involving the previously depicted objects (a monkey holding an umbrella). Finally, the participant was shown the initial cue cards and asked to identify the missing objects. Scores ranged from 0 to 6 for a trial. The trial was repeated if the participant made any mistakes the first time, thus resulting in the total possible score of 12. All participants scored above the cut-off value of 7, with the mean score of 11.8 (sd = 0.56).
 6. *Prospective memory*: The Cambridge Prospective Memory Test (CAMPROMPT) (Wilson et al., 2005) was used to assess the participant's prospective memory. The test requires the participants to accomplish three event-based and three time-based items. In between, the participant was given general knowledge quizzes and puzzles, which serve as ongoing tasks. The total score consists of a score for time-based and event-based tasks, each with a maximum of 18. Therefore the total CAMPROMPT score is out of 36, with higher scores reflecting better PM performance. The two versions of the test (A and B) were administered alternatively: version A was administered in Sessions 1 and 9, while version B was administered in Sessions 2 and 10.
 7. *Memory functioning*: The verbal paired associates (PA) was used to assess the participant's episodic memory. The test measures the ability to remember pairs of words, with the maximum score of 32. There were four versions of the PA test, each version being administered only once (in sessions 1, 2, 9 and 10). Each PA version contained 8 pairs, presented four times in different orders.

Design and procedure

The study was based on an experimental design with repeated measures including one condition. Due to difficulties related to recruiting participants, we were not able to include a control group in our study. Instead, our participants have served as their own control. The participants' PM was assessed (using CAMPROMPT) in Session 1, and then two weeks later in Session 2. There was no treatment between sessions 1 and 2. This allowed us to establish a baseline, which we then used to compare the PM performance of the participants after the treatment.

The study consisted of ten individual sessions per participant, as summarized in Table 1. In Session 1, the participants gave written consent, and were tested to determine whether they met our inclusion criteria. Session 2 was scheduled two weeks after the first session, to ensure a stable baseline allowing us to track their PM after this initial period. Sessions 2–9 were each 1 h long, and were scheduled twice per week over four weeks (two or three days apart).

The participants completed the visual imagery training in Sessions 2–4, followed by videos in Sessions 5 and 6. There were four different videos, presented to the participants in a random order. In Sessions 4 and 5, the participants were also introduced to the VR environment and were given sufficient time to familiarize themselves with the virtual house and using the joystick for navigation and interacting with objects. Sessions 6–9 involved practice in the VR environment. At the end of Session 9, the participant's PM was again assessed using CAMPROMPT, which allowed us to measure the effectiveness of the treatment. The last session was held four weeks later, and included a repeated assessment of the participant's PM.

The PM rehabilitation treatment consisted of computer-based training based on visual imagery, followed by practice in a VR environment. We present the visual imagery training first, followed by a description of the VR environment.

Table 1
Summary of the experimental sessions.

Session	Activities
1	Initial testing
2	Testing (CAMPROMPT, PA); Visual imagery levels 1–2
3	Visual imagery levels 3–6
4	Visual imagery levels 7–9; Familiarization with the VR environment
5	Practice video; Videos 1–3; Familiarization with the VR environment
6	Video 4; VR problems 1–4
7	VR problems 5–8
8	VR problems 9–12
9	VR problems 13–14, Testing (CAMPROMPT, PA)
10	Final testing (CAMPROMPT, PA), questionnaire

Table 2

Summary of the visual imagery training.

Level	Pairs	Provided per pair	Provided for testing	Score (all pairs)	Test score
1	Two nouns	Images/words + combined image	Word + image	93.75 (11.33)	95.33 (11.25)
2	Two nouns	Images/words only	Word + image	90 (19.59)	90 (22.36)
3	Two nouns	Words + 1st image	Word + image	95 (9.51)	94 (12.98)
4	Two nouns	Just words	Word	91.25 (19.45)	89.33 (21.2)
5	Noun + action	Words + 1st image	Word + image	98.33 (4.99)	98 (5.6)
6	Noun + action	Words only	Word	97.08 (5.72)	96.67 (7.24)
7	Cue + action	Text + image	Text + image	90.83 (13.33)	92 (14.24)
8	Cue + action	Text only	Text	92.92 (9.99)	97.33 (5.94)
9	Cue + action	Text only	Text	92.92 (8.79)	92.67 (12.23)

Visual imagery training

The aim of our computer-based training was to teach participants to remember a list of tasks with their associated cues using visual imagery as a mnemonic strategy. The training was presented on a computer in the form of a set of pages, which contained audio, images, video, written text, navigation buttons, and a replay button. Sometimes participants were asked to interact with the page (e.g. during testing). On such pages, buttons were provided for the user to record the answers (by speaking into the microphone).

During training, participants gradually progressed from remembering individual pairs of words to remembering complex, real-world tasks. The training contained 9 levels, with gradually reduced support for creating visualizations so that the user became more independent. Table 2 provides a summary of activities performed on different levels of the visual imagery training. At each level, the user first received guidance in order to visualize three pairs of words/tasks on which he/she was then tested, followed by unguided memorization and testing on further five pairs.

Initially, participants were introduced to visual mnemonics by being shown how to form mental images in order to remember a list of paired words. For example, for the pair (*rabbit, pipe*), the participant was first shown words and pictures of a rabbit and a pipe (Fig. 1), and they listened to the recording of the following text: *Look at the image displayed of a rabbit. Imagine its bristly fur and its long ears wriggling. Really focus on it, like it's right there in front of you. Now look at the picture of a pipe. Imagine this in your mind. Smoke is coming out of the pipe, giving off a smoky smell. Imagine grasping the pipe, and feeling it. The pipe feels round and smooth in your hands. The more senses you use, the more memorable the image will be.*

The following training page (Fig. 2) displayed the two previously shown pictures of a rabbit and a pipe, and also the combined picture, and played the recording of this text: *Now that you have imagined the two images individually, we are going to visually link them together, which will help you to remember them. This technique of visually linking them together will allow you to recall the individual words in the future. So, what I want you to do right now is to imagine the rabbit smoking the pipe, like it is in the third image. Close your eyes and really think about it. The rabbit is puffing away and more and more smoke is coming out. In your mind, imagine the rabbit taking the pipe out and blowing a smoke ring and then putting it back in its mouth. What a silly rabbit! Ok, now open your eyes. Now that you've done this, the image of the rabbit smoking the pipe should be firmly in your memory, so that if we gave you the image of a rabbit, you would immediately think of it smoking a pipe, which will lead you to the second word: pipe!*

Instruction was designed to be as descriptive as possible to better aid the user's visualization. The user was encouraged to mentally add to the presented images, personalizing them and making them more concrete. After presenting the initial three pairs of words at level 1, the user was tested by presenting the first word and the corresponding image from each pair, and asking them to record the

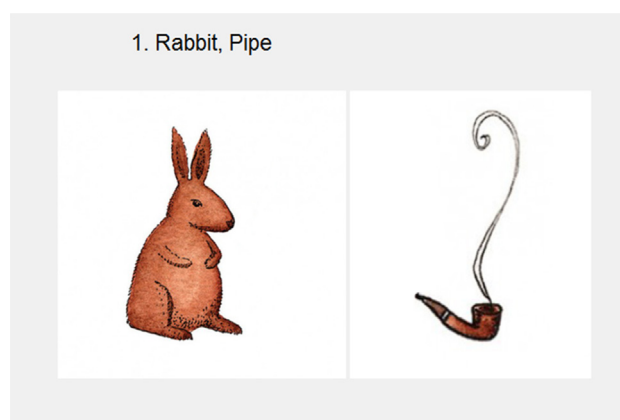


Figure 1. The screenshot from the visual imagery training, showing a pair of words.

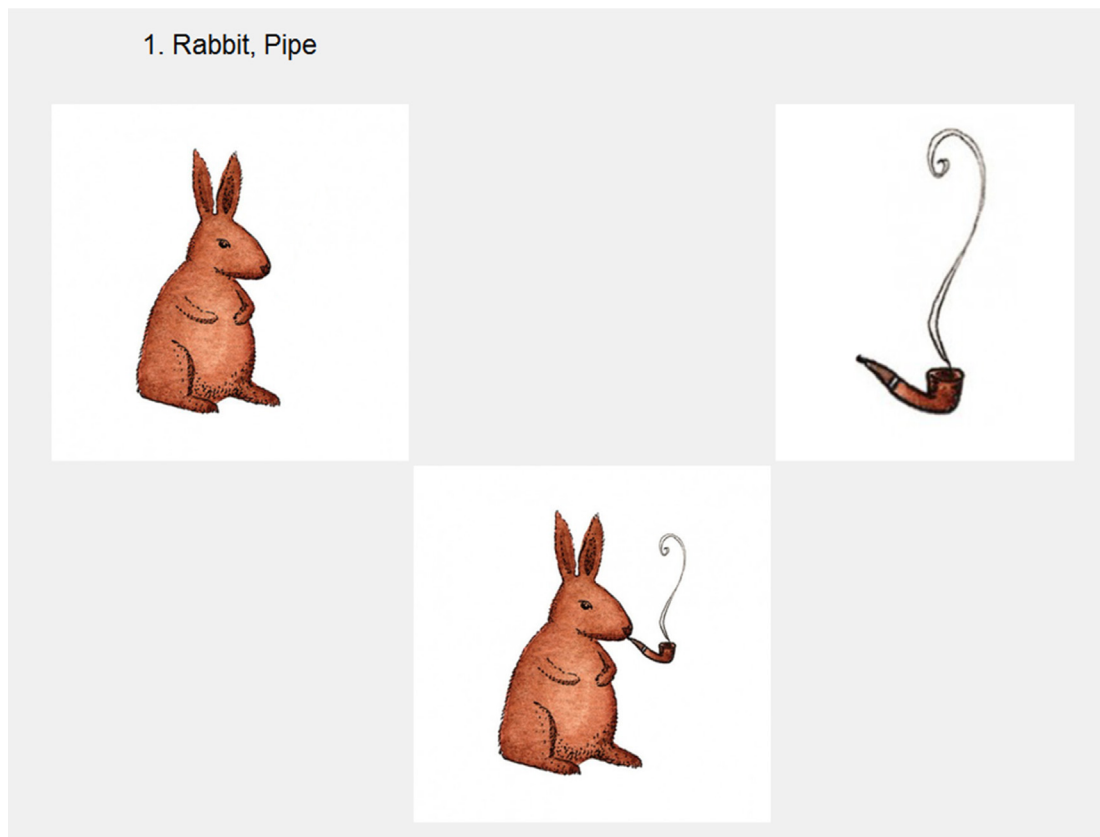


Figure 2. The combined image for the first word pair.

other paired word. Next, the user was presented with five pairs at once (Fig. 3), which he/she needed to visualize. Please note that although the user was provided with the words, individual images and the combined images, the user was not guided in generating the combined image: he/she needed to think about the combined image. The user had 5 min to memorize the five pairs, but was free to go to the next page before that time was up; the user was then presented with the word/image for the first element of each pair and needed to record the second object from each pair (Fig. 4).

At level 2, users were provided with words and two individual images but the combined image was not provided. Participants were guided in the process of generating their own combined image for each training pair, and for testing pairs they needed to develop the visualizations themselves. At level 3, training became even more demanding, as the user was given only one image (for the first element of each pair). Users were taught that the more concrete (using real places, people, things, or real time), more detailed, more silly or humorous a combined image was, the more memorable it would be.

At levels 1–4, users needed to visualize pairs of nouns (such as *rabbit/pipe*). Levels 5 and 6 involved pairs consisting of a noun and an action (e.g. *Egg + make an omelet*), while at higher levels, each pair contained a cue and an action corresponding to PM time- or event-based tasks (e.g. *When you go past the green grocers, go in and buy strawberries*).

After completing all 9 levels of visual imagery training, the participants completed four problems that were presented in a random order for each participant. For each problem, the participants needed to memorize a list of 11 tasks, two of which were time-based tasks (e.g. *At 12:36, take your medication*), and the rest were event-based tasks (e.g. *At Auto Sound and Security, buy a steering wheel lock*). The participants had 11 min to memorize the tasks, and were instructed to use the visual imagery technique that they were taught. The task list was presented only once, followed immediately by a 25 second distractor task (mental arithmetic) to clear the working memory. This task was given to ensure that participants were not rehearsing the tasks or storing them in working memory. After the distractor task, the user was shown a 7 min video. At no other time (other than at the start of the problem) did participants have access to the list of tasks.

Each problem was based on a different scenario, and involved the video taken from a car traveling from destination A to destination B. All videos were taken in (*Name of the city removed for the blind review*), and involved shopping malls and public buildings the participants were familiar with. While watching the video, at the appropriate place in time (when the cues were present in the video or at a particular time), participants stopped the movie and recorded the task that was to be performed during that time. Each video only included ambient sounds; no cues or instructions were given verbally during the video. There were no concurrent tasks given to participants in addition to the PM tasks.

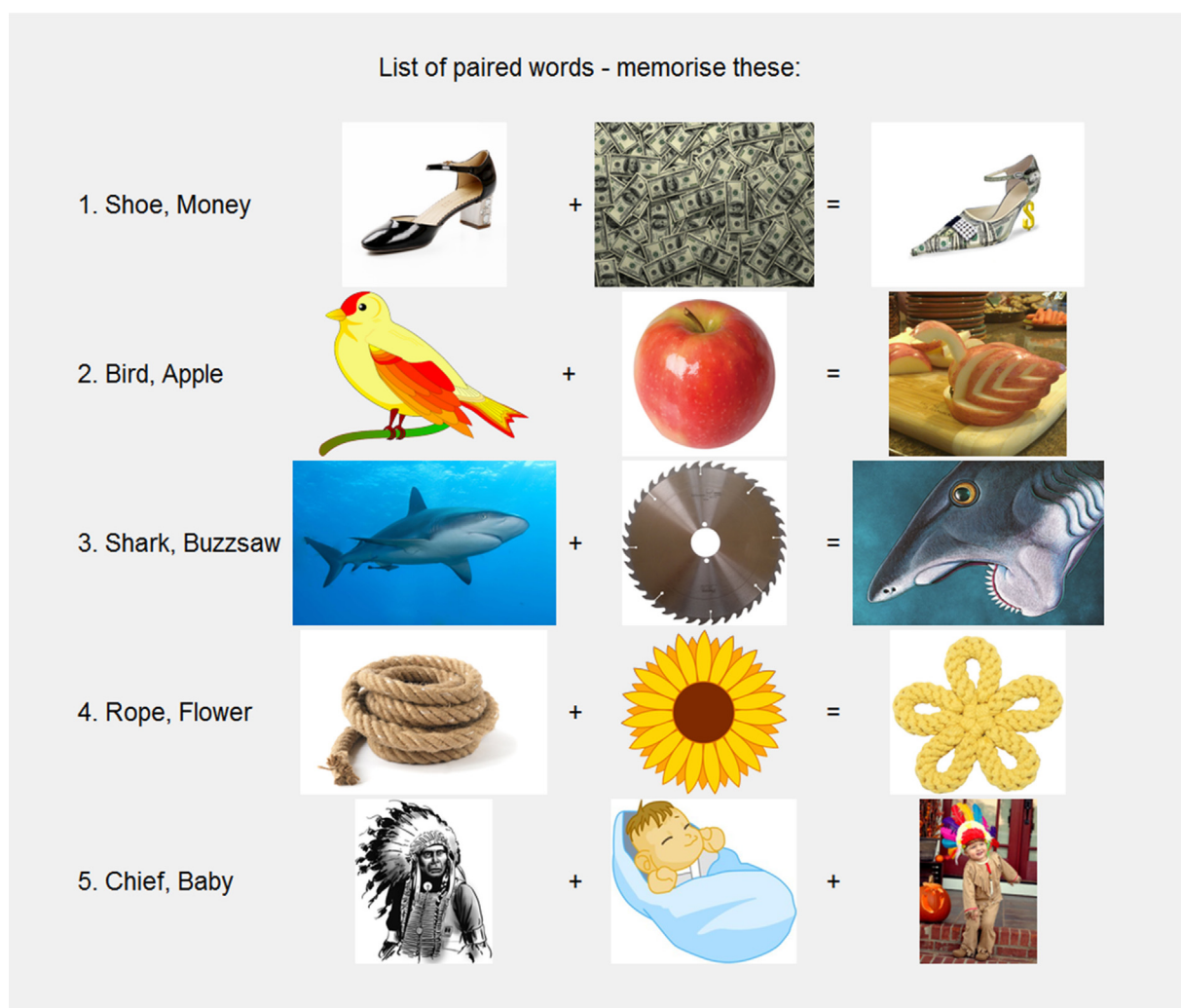


Figure 3. Memorizing five word pairs from level 1.

Virtual reality environment

After completing the visual imagery training, each participant started practicing PM tasks in the VR environment. We used the Unity² game engine to develop a VR environment, which represented a house with common household objects, and a garden.

At the beginning of a VR problem, the user was presented with a list of PM tasks to visualize. The maximum time allowed for visualization depended on the number of tasks (1 min per task), but the participants could stop whenever they wanted. After that, the participant was given a distractor task (30s of three-digit addition problems), and then could interact with the VR environment.

There were 14 problems presented in the fixed order in four separate VR sessions (Table 1). The initial VR problem had only three tasks to memorize (Table 3). The tasks varied in complexity: the ones in early problems consisted of a cue and a single action, such as *Turn on the radio at 3pm*. The number and complexity of tasks gradually increased, with the last problem having 8 tasks, some of which had more than one action to perform (e.g. task 4 in Problem 14 is *Once the cake in the oven is done, take it out and put it on the table*). Overall, there were 36 time-based and 36 event-based tasks in 14 problems.

Participants could perform various actions on objects in the VR environment, such as turning the TV on. To perform an action, the user needed to select the object first, and then specify the desired action from a menu. The user could view a clock (by pressing a button) whenever they wanted, which was necessary for time-based tasks. Certain tasks, such as taking the roast out of the oven, involved other objects, which were added to the inventory. Other tasks required inventory items to be collected beforehand. The user could view the inventory (by pressing a button) at any time.

The system maintained the list of active tasks. Time-based tasks became active 1 min before the stated time. Event-based cues only began when the stated event occurred. Consider the task: *Once the dishwasher is finished, take out the washed cutlery and*

² <https://unity3d.com/unity>.

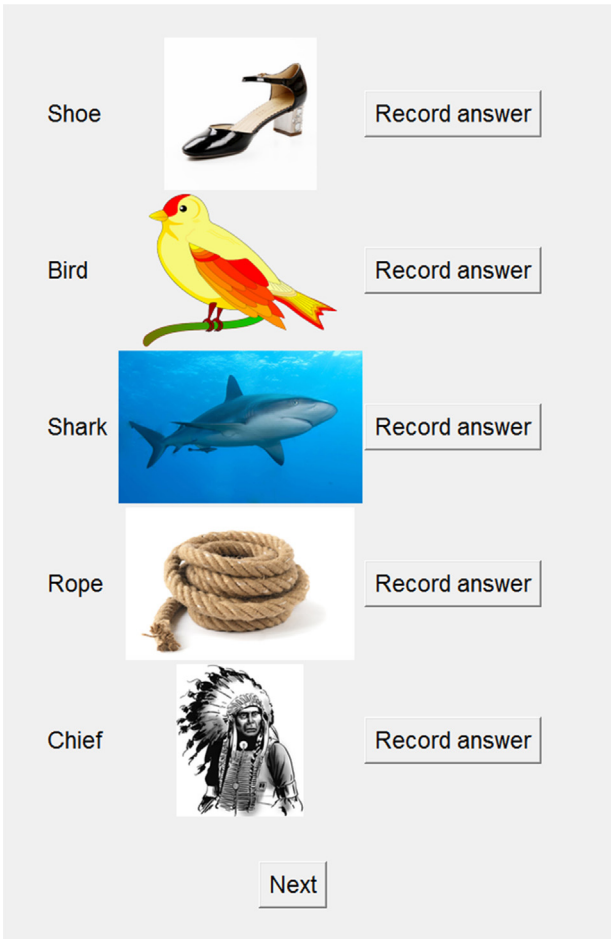


Figure 4. Testing phase from level 1.

set the table. For this task, the user has no way of knowing when exactly the dishwasher will finish, and so he/she cannot perform the action before the cue is discovered. For event-based and time-based tasks, the required completion time was 1 min or 2 min respectively.

Results

Fifteen participants (six females and nine males) completed all sessions. They were aged 45–82 (mean = 65, sd = 10). Ten participants reported their ethnicity as New Zealand European (NZE), one participant as both NZE and Māori, one as USA, and

Table 3
The list of tasks for VR problems 1 and 14.

Task #	Description
<i>Problem 1</i>	
1	At 10:01am, feed your pet by filling up their bowl.
2	When the phone rings, answer it.
3	At 10:04am, clean the shower.
<i>Problem 14</i>	
1	At 5:34pm, turn on the iron.
2	At 5:37pm, turn on the toaster.
3	Once the iron is hot enough (ding sound), iron the clothes.
4	Once the cake in the oven is done, take it out and put it on the table.
5	At 5:40pm, feed your pet by filling up their bowl.
6	If you start sneezing, use a tissue.
7	At 5:42pm, empty the wastebasket.
8	Once the toast has popped, eat the toast.

Table 4

Percentage scores (sd) on VR problems, overall and separately for Event-Based (EB) and Time-Based (TB) tasks.

VR problems	1–4	5–8	9–12	13–14
Overall score	32.22 (17.21)	43.58 (20.25)	42.02 (22.27)	44.58 (20.58)
Overall actions	77.22 (15.89)	78.5 (16.61)	78.45 (13.47)	72.5 (17.96)
EB score	30 (22.06)	45.56 (21.33)	34.86 (22.5)	35.83 (18.22)
EB actions	73.33 (24.94)	73.89 (21.5)	72.36 (17.22)	60 (22.76)
TB score	41.67 (20.95)	42.5 (26.03)	47.78 (27.91)	53.33 (27.73)
TB actions	81.67 (14.84)	85 (15.89)	83.89 (13.39)	85 (19.59)

the remaining two participants reported dual ethnicity with the primary one being NZE (the secondary being Canadian and Dutch respectively). Only two participants were employed, with the rest being either unemployed or retired. The highest qualification for five participants was on the high-school level, while the remaining ones had tertiary qualifications, including one PhD, two Master degrees, one Postgraduate Diploma and six Bachelor degrees.

Table 2 reports the percentage scores from the visual imagery training. As discussed previously, at each level of the visual imagery training the participants received three guided pairs, followed by five unguided pairs. Table 2 presents the average scores at various levels, for both guided and test pairs (overall mean 93.57%), and using only test pairs (93.93%). The scores are high, showing that the participants were successful in using visual imagery to memorize the pairs. As training started with easier pairs and more support, it is pleasing to see the participants maintaining high scores at later levels.

Scores from the VR sessions

We report the average scores for problems per VR session in Table 4. The table presents the scores for all tasks, and then separately scores for the event-based (EB) and time-based tasks (TB). If the task was completed at the correct time (i.e. while the task was active), the participant was given 1 mark. No marks were given for tasks performed when they were not active. We also include scores that report the percentage of actions performed correctly (*Overall actions*, *EB actions* and *TB actions*), disregarding whether cues were recognized correctly or not. The action scores are consistently higher than overall scores by 25–40%, for both types of PM tasks, showing that our participants have not found time-based tasks harder in comparison to event-based tasks.

The one-way repeated measures ANOVA revealed a statistically significant difference on the overall scores, $F(3, 42) = 3.006$, $p < .005$, partial $\eta^2 = .177$. The only two significantly different scores are those from the two initial VR sessions ($p < .05$, $d = 0.58$), with the participants achieving significantly higher scores on problems 5–8 than on problems 1–4.

A two-way repeated measures ANOVA was run to determine the effect of different task types over sessions on the participants' performance in the VR environment. There was a statistically significant interaction between task type and session on score, $F(3, 42) = 2.968$, $p < .05$, partial $\eta^2 = .175$. There was no significant effect of session on either event-based task scores ($p = .126$) or time-based task scores ($p = .138$). The difference between mean time-based and event-based scores was not significant for the first two VR sessions. However, there was a significant difference between the mean time-based and event-based scores for problems 13–14 ($t = 1.71$, $p = .03$, $d = 0.71$), and a marginally significant difference for problems 9–12 ($t = 1.7$, $p = .09$, $d = 0.5$).

CAMPROMPT and PA scores

The CAMPROMPT test was administered in sessions 1, 2, 9 and 10. The CAMPROMPT scores from session 1 for our population included one participant's PM classified as impaired, four as poor, six as average, two as above average and two as very good PM. A one-way repeated measures ANOVA revealed that the overall CAMPROMPT scores (reported in Table 5) were significantly different, $F(3, 42) = 12.28$, $p < .005$, partial $\eta^2 = .47$. The scores remained at a constant level between sessions 1 and 2 (two weeks apart), thus showing that the PM level is stable without treatment. There was a sharp increase in session 9, post-intervention

Table 5

The average scores (sd) on the paired associates test and CAMPROMPT.

Session	Paired associates	CAMPROMPT	CAMPROMPT Time-based	CAMPROMPT Event-based
1	13.2 (8.63)	25.13 (5.39)	12.47 (3.18)	12.67 (3.85)
2	17.2 (10.63)	25.07 (6.24)	12.20 (4.23)	12.87 (3.14)
9	15.33 (9.27)	31 (3.32)	15.53 (2.36)	15.47 (2.07)
10	20.8 (9.47)	30.6 (4.20)	15.33 (2.38)	15.27 (2.46)

($p < .05$, $d = 1.03$). The CAMPROMPT scores then remained the same in the final session (four weeks later), which is a significant achievement. Table 5 also reports the CAMPROMPT scores for the time- and event-based tasks separately. A two-way repeated measure ANOVA identified no significant interaction between task type and session ($p = .925$), and there was no main effect of task ($p = .746$).

The PA scores are reported in Table 5. There was a lot of variance, with one participant never scoring more than 3, and another participant always scoring 28 or higher. The PA scores improved over time, with the highest scores being reached in Session 10. A one-way repeated measures ANOVA revealed that the PA scores were significantly different, $F(3, 42) = 7.19$, $p < .005$, partial $\eta^2 = .34$. There were statistically significant differences in scores between sessions 1 and 2 ($p < .05$, $d = 0.41$), and between sessions 1 and 10 ($p < .01$, $d = 0.78$).

Discussion

The primary aim of our project was to develop a computerized PM rehabilitation approach for stroke survivors. We developed a computer-based training that teaches stroke survivors to memorize PM tasks using visual imagery, and a VR environment in which they can practice their PM skills in a safe and realistic environment. The visual imagery training aimed to strengthen the association between cues and actions, in order to induce automatic recall of intention later (Chasteen, Park, & Schwarz, 2001; Potvin et al., 2011).

A lab study with 15 participants was conducted to test our hypotheses. Analyses of the data collected from the VR environment showed that the participants improved their performance during the study, thus confirming our first hypothesis. Furthermore, our second hypothesis was also confirmed. The participants' PM improved significantly after visual imagery training and VR practice, as measured by the CAMPROMPT test. Even more importantly, a delayed CAMPROMPT test, administered four weeks after the VR practice, showed that the improvement was stable. The participants improved their CAMPROMPT scores on both event- and time-based tasks.

The findings of our study include not only an improvement in PM but also an increase in PA scores. A potential explanation of increased PA scores is that the participants used the visual imagery to memorize the pairs of words presented in the PA tests, which strengthened the cue-action association and resulted in improved encoding. This explanation is consistent with findings that visual imagery can improve retrospective verbal episodic memory (Kaschel et al., 2002) and results in improvement on recall measures in paired-associate learning tasks (Lewinsohn et al., 1977).

Previous studies of PM reported higher performance on event-based tasks than time-based tasks (Groot, Wilson, Evans, & Watson, 2002). In our study, however, participants performed better on time-based tasks than on event-based tasks in the VR environment. Potvin et al. (2011) reported better improvement on delayed cue recall for time-based tasks than for event-based tasks when using visual imagery for PM rehabilitation. Their visual imagery training explicitly included time-based tasks; similarly, our computer-based training also required the participants to form mental images associating a specific time with an action. Therefore, visual imagery might have strengthened encoding of time-based tasks.

We also received informal subjective feedback from the participants, who found the visual imagery technique easy to use. The majority of the participants reported enjoying the VR environment, but some found the joystick difficult to use initially. Additionally, the participants reported that their memory improved in general.

The limitations of our study include the small number of participants, and the lack of control group, both due to the difficulties in recruiting participants. Our experiment design included the initial period of two weeks with no treatment, which helped to determine the baseline for PM functioning. However, this design is not ideal, as each version of the CAMPROMPT test was administered twice: version A in Sessions 1 and 9 (6 weeks apart), and version B in Sessions 2 and 10 (8 weeks apart). Although repeated use of each CAMPROMPT test was separated by several weeks, there might have been a learning effect related to repeated assessment.

Practical Applications

In contrast to some existing approaches for PM rehabilitation which rely on compensatory strategies (such as diaries), our approach is based on a cognitive strategy (visual imagery) which can be used in everyday situations. A distinctive feature of our treatment is that it does not require a clinical setting; the participants learned the cognitive strategy via computer-based training. Although the treatment was short and of low intensity, it resulted in a significant increase in PM. Our treatment does not require human (other than the participant) input, which opens a potential for wide application of the approach. Turning our treatment into an online service would make PM rehabilitation available anywhere and at any time, to a wide population of stroke patients.

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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